THEORETICAL EXAMINATION
December 6, 2010
Abuja, Nigeria

THEORETICAL EXAMINATION RULES

1. All competitors must be present at the front of examination room ten minutes before the examination starts.
2. No competitors are allowed to bring any tools except his/her personal medicine or any personal medical equipment.
3. Each competitor has to sit according to his or her designated desk.
4. Before the examination starts, each competitor has to check the stationery and any tools (pen, ruler, calculator) provided by the organizer.
5. Each competitor has to check the question and answer sheets. Raise your hand, if you find any missing sheets. Start after the bell rings.
6. During the examination, competitors are not allowed to leave the examination room except for emergency case and for that the examination supervisor will accompany them.
7. The competitors are not allowed to bother other competitor and disturb the examination. In case any assistance is needed, a competitor may raise his/her hand and the nearest supervisor will come to help.
8. There will be no question or discussion about the examination problems. The competitor must stay at their desk until the time allocated for the examination is over, although he/she has finished the examination earlier or does not want to continue working.
9. At the end of the examination time there will be a signal (the ringing of a bell). You are not allowed to write anything on the answer sheet, after the allocated time is over. All competitors must leave the room quietly. The question and answer sheets must be put neatly on your desk.

Read the following instructions carefully:

1. The time available is 3 hours.
2. The total number of the questions is 3. Check that you have a complete set of theoretical questions and the answer sheet.
3. Use only the pen provided.
4. Write down your name, code, country and signature in the first page of your answer sheet. You will only need to write down your name and code in the next pages of your answer sheet.
5. Read carefully each problem and write the correct answer in the answer sheet.
6. All competitors are not allowed to bring any stationary and tools provided from outside. After completing your answers, all of the question and answer sheets should be put neatly on your desk.

Grading rules**:** According with each question marking scheme.

THEORETICAL QUESTIONS

PROBLEM 1: SOLAR RADIATION

It is well known that fossil fuel based sources of energy are exhaustible. As such, over the years attempts have been made to source, harness and develop other sources of energy. These alternative energy sources may include solar energy, wind energy, nuclear energy and energy from biomass among others.

The sun, which is the source of solar radiation, is a sphere of intensely hot gaseous matter with an effective blackbody temperature of about 5800 K. The sun has a diameter of about 1.40×10^9m at a distance of about 1.5×10^{11}m from the earth. The temperature in the core of the sun has been estimated to be between 8×10^6 and 40×10^6 K. It is believed that the sun is a continuous fusion reactor in which several fusion processes occur. The fusion process, usually considered most useful, is a process in which four hydrogen nuclei combine to form a helium nucleus. The mass of the helium nucleus is less than that of the four hydrogen nuclei, this mass defectin the reaction appears as energy released. The energy released is given by $E=mc^2$, m is the mass and c is the speed of light. This energy is transported to the surface from where it is radiated into space. Radiation reaching the earth's surface has two components- direct and diffuse.

Nigeria is in the tropics where solar energy is available in abundance. Therefore, if properly harnessed, solar energy could serve as the much desired alternative energy source for industrial and domestic uses. There is however, dearth of basic data on available solar radiation to enable incorporation in national planning. To this end, many measurements have been made to estimate the available solar radiation. This has also led to the establishment of models for predicting solar radiation in various locations in the country.

In an experiment to determine available solar radiation (insolation), in Abuja, Nigeria, a cadmium sulphide (CdS) photoresistor was used. When solar radiation is incident on the photoresistor its resistance decreases. By proper choice of resistances in a Wheatstone bridge apparatus, the resistance R of the photoresistor can be obtained. The readings obtained are displayed in Table 1.

Table 1

Resistance R (Ohm)	1	2	3	4	5	6	7	8	9	10
Solar radiation, S (Wm^{-2})	3777	1513	886	606	451	355	290	243	208	180

The CdS photoresistor obeys the relation

$$SR^{\alpha} = \beta \qquad (1)$$

Where,
R is photoresistance in ohms, obtained from the Wheatstone bridge apparatus,
S is the solar radiation in Wm^{-2},
α and β are constants.

Constants

1 u = 1.66×10^{-27} kg

c = 3.0×10^{8} ms^{-1}

Planck's constant, h = 6.63×10^{-34} Js

Questions

(1.1) The fusion process is represented by the equation

$$4\,{}^{1}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + 2\,{}^{0}_{1}\mathrm{e}^{+} + \text{neutrino}$$

Given that the mass of a hydrogen atom (${}^{1}_{1}\mathrm{H}$) = 1.00794 u and the mass of helium atom (${}^{4}_{2}\mathrm{He}$) = 4.002602 u, and neglecting the masses of positrons and neutrino, calculate the mass defect in kilograms (kg) and the energy in Joules (J) released during the fusion reaction. ***(0.7 Mark)***

Irradiation of an absolute black body, like the sun, is given by $P=A\sigma T^4$, where P is the power, A is the surface area of the black body, T is the absolute temperature of the black body, and σ is the Stefan-Boltzmann's constant.

(1.2) The solar constant is the amount of incoming solar radiation per unit area, per unit time just before entering the atmosphere, in a plane perpendicular to the rays. Assuming that Stefan-Boltzmann's constant (σ) = 5.7×10^{-8} $Wm^{-2}K^{-4}$, estimate the value of the solar constant. ***(1.5 Marks)***

(1.3) What is the approximate time (in minutes) it takes radiation from the sun to reach the earth's surface? ***(0.4 Mark)***

(1.4) Suppose energy of one photon of solar radiation is 3.87×10^{-19} J. Calculate the wavelength of this radiation. ***(0.5 Mark)***

(1.5) Rewrite equation (1) in logarithmic form that will enable you determine the constants α and β from a graph of $\log_{10}S$ versus $\log_{10}R$. ***(0.4 Mark)***

(1.6) Use the equation obtained in question 1.5 and the data provided in Table 1 to plot a linear graph. ***(4.5 Marks)***

(1.7) Write the equation of the graph plotted. ***(1.0 Mark)***

(1.8) Deduce the values of α and β. ***(1.0 Mark)***

Problem 2: Application of Sulphuric Acid in Industries

The consumption of sulphuric acid (H_2SO_4) is usually an index of a country's industrial development, because of its extensive use in a large number of manufacturing operations. It is a highly corrosive, dense, oily liquid, with colourless to dark brown colour depending on its purity. This is produced on a large scale by two commercial processes, the Contact process and the Lead-Chamber process. In the Contact process, sulphur (IV)oxide is converted to sulphur(VI) oxide, in the presence of vanadium(V)oxide promoted by molybdenum oxide at 450^0C and 1-2 atmospheric pressure. The sulphur(IV)oxide is oxidised to sulphur(VI)oxide by vanadium(V)oxide. In the process, the vanadium(V)oxide is reduced to Vanadium(III)oxide then re-oxidised. This is a good example of the way a catalyst can be changed during the course of a reaction. In the absence of vanadium(V)oxide as a catalyst, the reaction is very slow. Sulphur(VI)oxide is converted to oleum($H_2S_2O_7$ - sulphuric acid and sulphur(VI) oxide) by dissolution in sulphuric acid. The oxidation of sulphur(IV)oxide to sulphur(VI)oxide in the Contact Process is an exothermic reaction.

Concentrated sulphuric acid has a very strong affinity for water and is sometimes used as a dehydrating agent. It reacts with sucrose, leaving a brittle spongy black mass of carbon. The acid reacts similarly with skin tissue, cellulose, plant and animal matter. Sulphuric acid is formed naturally in mines by the oxidation of sulfide minerals, such as iron(II)sulfide (FeS). The aqueous solution formed when such sulphide minerals dissolve is acidic and is capable of dissolving metal ores. The resultant solution is a brightly colored toxic stream.

During combustion, sulfide minerals in fossil fuels produce sulphur(IV)oxide which is given off to the Earth's atmosphere. The sulphur(IV)oxide can be converted to sulphur(VI)oxide by radiation from the sun and can be transformed into sulphuric acid during precipitation(rainfall).

The lead-chamber process depends upon the oxidation of sulfur(IV)oxide with nitric acid (HNO_3) in the presence of steam.

Questions

2.1 Choose the <u>two</u> correct options from A-F, why it is not commercially suitable to dissolve SO_3 directly in water to give concentrated sulphuric acid? **(*0.40 mark*)**

Option	Solution
A	To reduce the hazards of spillage
B	Because the density of the product is too high
C	To minimise transport costs of large volumes
D	Because the last step of the process is too expensive
E	Because the last step of the process is too exothermic
F	An aerosol of the sulphuric acid rapidly fills the container

2.2. Match the role that sulphuric acid plays in manufacturing with each of the following industrial activities as shown below:

(i) Electroplating of iron and steel **(*0.25mark*)**

(ii) Fertilizer industry **(*0.25mark*)**

(iii) Manufacture of detergents **(*0.25mark*)**

(iv) Automotive industry **(*0.25mark*)**

Option	Industrial Role
A	Sulphuric acid dissolves the iron and steel
B	Dissolution of phosphate rocks
C	Manufacture of lead acid accumulators
D	Cleaning of metal surfaces by dissolution of oxide layers
E	Functionalization of compounds with SO_3^- groups

2.3. Write balanced equations for the four major reactions in the Contact process.

(*2.0marks*)

2.4. Choose one option from A-C, why vanadium(V)oxide is suitable for use as a catalyst in the Contact process **(*0.25mark*)**

A. Vanadium(V) oxide removes electron from SO_2 and is re-oxidised by oxygen.

B. Vanadium (V) oxide supplies electrons to SO_2 and is in turn reduced to vanadium (III) ions.

C. Vanadium (V) oxide reacts with oxygen to give a complex which is regeneratable.

2.5. Use appropriate ionic equations to show the reduction and re-oxidation of the vanadiumions **(*1.0mark*)**

2.6. If the Contact process is 80% efficient, calculate the weight of 98% sulfuric acid produced from 100 kg of pure sulphur. Assume 100% conversion of sulphur to sulphur(IV) oxide. (S = 32.0, H = 1.0, O = 16.0 and the density of 98% sulfuric acid is 1.98g/cm^3). ***(1.0mark)***

2.7. Write a balanced equation for the reaction of excess sodium chloride and concentrated sulfuric acid. **(*0.5mark*)**

2.8. Write a balanced equation representing the dehydration of sucrose by concentrated sulphuric acid. The formula for sucrose is $C_{12}H_{22}O_{11}$ **(*0.5mark*)**

2.9. Sulfuric acid is a diprotic acid. Write equations to show its ionization in water

(*0.5mark*)

2.10. Determine the volume of gas produced in the first stage of the Contact process when 200 g of sulphur is converted to sulphur(IV) oxide at 300^{o}C and 1 atmosphere pressure. Assume the conversion of sulphur to sulphur(IV) oxide is 100%).R = 0.082 *l*-atm mol^{-1} K^{-1} **(*1.25 marks*)**

2.11. What volume of 0.20mol.dm^{-3} sulphuric acid is required to neutralise completely 25cm^{3} of 16.0g of sodium hydroxide dissolved in 0.25 dm^{-3} of water? (Na = 23.0, O = 16.0, H = 1, S = 32.0) ***(0.5 mark)***

2.12. From the list supplied below, select three (3) fuels that will give the most acid rain.

(0.5 mark)

a) Firewood b) petroleum c) coal d) biodiesel e) bioethanol f) natural gas

Problem 3: Animal Ecology

In an ecological study, Petersen method is the simplest mark-recapture for estimating animal population size. The procedure is to mark a number of individuals over a short time, release them, and then recapture individuals to check for marks. The second sample must be a random sample for this method to be valid; that is, all individuals must have an equal chance of being captured in the second sample regardless of whether they are marked or not. The data to be obtained are;

M = Number of individuals marked in the first sample
C = Total number of individuals captured in the second sample.
R = Number of individuals in second sample that are marked.
From these three variables, we can obtain an estimate of population size (N) at the timeof marking. Therefore,

$$N = \frac{(M)(C)}{(R)}$$

This formula assumes sampling without replacement in the second sample, so any individual can only be counted once.

Catfish (*Clariasgariepinus*) is a common fish species in Nigeria and it is a relished source of animal protein in the diet of many urban dwellers.
A group of students carried out an ecological investigation in a small lake (approximately 100 m x 60 m) to estimate the size of the population of catfish (*Clarias*sp.*)* that would be subject to fishing during a proposed fishing expedition. They marked109 catfish. In a second sample, a few days later, they caught 177 fish of which 120 fish were not marked.

3.1. Complete the table below ***(0.5 mark)***

Number caught and marked in first sample (M)	Total caught in second sample (C)	Number marked in second sample (R)

3.2. What was the population size of catfish in the lake?(*show your workings*) ***(1.0 mark)***

3.2.1 Which of the following reasons directly invalidates the assumption that the marking process does not affect the chance of them being captured in the second sample: ***(0.5 Mark)***

	Reason:	**True**	**False**
1.	The marking procedure makes the animal more conspicuous to predators.		
2.	There is an increase in the number of predators.		
3.	The marking process is toxic/ harmful to the animal.		
4.	A toxic chemical is introduced into the environment.		

3.3. There are several species of earthworm in Nigeria and they are often used as the preferred baits in fishing. Some ecology students were to obtain earthworms for baiting duringthe fishing expedition from a designated courtyard in the school compound.Castingactivities of earthworms enhance the productivity of the terrestrial ecosystem. As the earthworms burrow into the soil they literally eat their way through and the ingested earth is passed through the digestive tract and eventually deposited at the surface in small mounds or castings. This activity of the earthworms plays important roles in increasing soil fertility and productivity. When the students observed the way the earthworm casts were distributed in the courtyard, they came up with the hypothesis that the observed earthworm casts followed a random spatial distribution.To test this hypothesis they placed quadrats of the same dimension randomly in the courtyardand the numbers ofearthworm castsfound in 100 chosen quadrats were counted as follows:

Number of earthworm casts(x)	0	1	2	3	4	5	6	7	8	Total
Number of quadrats (frequency, f)	17	20	28	18	8	8	0	0	1	100

If the distribution followed a **random distribution** , it was expected that the **variance to mean ratio** ($s^2/\bar{x}$) **would be equal to 1.**

3.3.1. Calculate the mean ($\bar{x}$) number of earthworm casts per quadrat. ***(1.0 mark)***

3.3.2. Calculate the variance (s^2) and determine the variance tomean ratio

$$S^2 = \frac{\sum_{i=1}^{n} f(x_i - \bar{x})^2}{N-1}$$ ***(1.0mark)***

3.3.3. From your answer to **3.3.2** above, which of the observations below is correct: ***(0.5 mark)***

Option	**Variance-to-mean ratio ($s^2/\bar{x}$)**	**Conclusion**	**Tick (√) appropriate box below**
I	0.8 – 1.2	The distribution closely follows a random pattern.	
II	>1.2 or <0.8	The distribution does not follow a random pattern.	

3.4. One measure of biodiversity is the number of species in an area. Nigeria is one of the countries in Africa with highly diverse bio-resources. There are over 10 species of earthworms that have been reported in Nigeria and their distributions vary from one ecological zone to another. One widely used index of diversity of organisms in an area is provided by the following formula:

$$d = \frac{N(N-1)}{\sum_{i=1}^{n} n_i\ (n_i - 1)}$$

where N is the total number of organisms of all species, n_i is the total number of organisms of i species and $\sum$ symbol for summation.

A group of students collected 50 individual earthworms from a snail farm and after counting, the following data in the table below were obtained:

3.4.1. Complete the Table below (**1.0 mark**)

Species of earthworm	**No. collected**	**n(n-1)**
Eudriluseugeniae	10	
Hyperiodrilusafricanus	15	
Lybodrilusviolaceus	16	
Alma millsoni	9	
Total (N)	50	
		$\sum_{i=1}^{n}$ =

3.4.2. Determine the diversity (d) of earthworms in the snails farm. ***(1.0 Mark)***

3.4.3. When the earthworms eat their way through the soil, they make channels, and the soil will contain more air, so more oxygen.

The following statements refer to the role of the oxygen in the soil.

Answer each question with true or false, according to the table.Mark X into the boxes

(1.0 Mark)

	True	False
a) plant roots do notabsorb oxygen from the soil because it is transported from the leaves		
b) earthworms themselves use the oxygen from the soil		
c) bacteria who transform the ammonia produced by animals into nitrate, need the oxygen from the soil		
d) Oxygen from the soil is necessary for the decomposition of the organic matter		

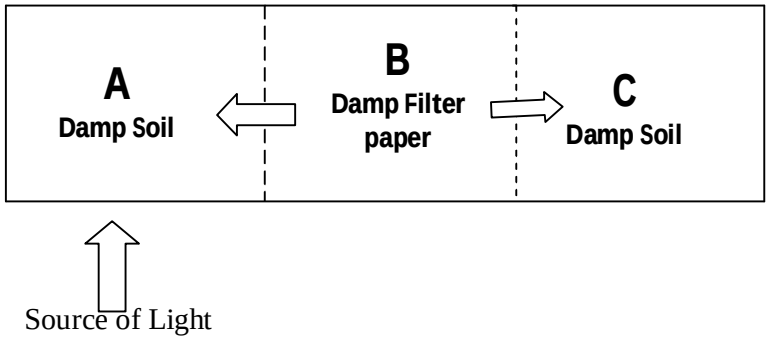
3.4.4. The earthworm casts consist of compounds containing elements. Plants need elements. Which of the elements contained in the casts, is the most important for the plant to take up using their roots? ***(0.5 Mark)***

Choose one of the following elements: O, C, N, H

Answer: _____

3.5A scientist conducted an experiment to investigate the response of earthworms (*Hyperiodrilus* sp.) to different light colours by measuring the weight of casts produced on weekly basis for a period of three weeks by the worms in the lighted and dark compartments of the experimental box as shown in the diagram below. Eighty earthworms were introduced into the central portion (B) of the box containing damp filter paper. The mean weight of casts in compartments A and C were recorded as presented in the Table below.

Experimental Box



Colour of light	**No. of *Hyperiodrilus* sp. exposed**	**Mean weight (g) of cast produced in the portion of box with light (A)**	**Mean weight (g) of casts in the dark portion of the box (C)**
White (W)	80	4.8	19.5
Green (G)	80	9.4	30.4
Red (R)	80	11.9	16.1
Blue (B)	80	10.6	30.5

3.5.1. Use the data in the table to present this information by drawing a suitable graph. ***(1.5 Marks)***

3.5.2. From the graph which of the observations below is/are the most probable conclusion(s).Tick the correct boxes ***(0.5 Mark)***

(i) The red colour induced the highest amount of casts produced in the lighted portion, the least amount of casts in the dark portion. ☐

(ii) Colour of light has no effect on the behavioral responses of worm to light exposure. ☐

(iii) *Hyperiodrilus* sp.could not diffentiate between the different light colours. ☐

(iv) Green colour induced the highest amount of casts produced in the dark portion. ☐